Metcalf, S.J., Moyle, K. and Gaughan, D.J. (2010) Qualitative analysis of recreational fisher response and the ecosystem impacts of management strategies in a data-limited situation. Fisheries Research, 106 (3). pp. 289-297.

Accepted Manuscript

Title: Qualitative analysis of recreational fisher response and the ecosystem impacts of management strategies in a data-limited situation

Authors: S.J. Metcalf, K. Moyle, D. Gaughan

PII: S0165-7836(10)00197-9
DOI: doi:10.1016/j.fishres.2010.08.008
Reference: FISH 2999

To appear in: *Fisheries Research*

Received date: 10-9-2009
Revised date: 17-8-2010
Accepted date: 17-8-2010

Please cite this article as: Metcalf, S.J., Moyle, K., Gaughan, D., Qualitative analysis of recreational fisher response and the ecosystem impacts of management strategies in a data-limited situation, *Fisheries Research* (2010), doi:10.1016/j.fishres.2010.08.008

Qualitative analysis of recreational fisher response and the ecosystem impacts of management strategies in a data-limited situation

S. J. Metcalf[1,2] K. Moyle[3] and D. Gaughan[1]

[1] Western Australian Fisheries and Marine Research Laboratories, Department of Fisheries, PO Box 20, North Beach, Perth, Western Australia, Australia 6920
[2] School of Biological Sciences and Biotechnology, Murdoch University, South Street, Murdoch, Western Australia, Australia 6150
[3]Recfishwest, PO Box 34, North Beach, Perth, Western Australia, Australia 6920

Corresponding author: Sarah Metcalf, ph. +61 8 9203 0144, fax. +61 8 9203 0199
sarah.metcalf@fish.wa.gov.au

Abstract

The behavioural responses of recreational fishers to changes in fisheries management are rarely investigated and as a result may be poorly understood. Changes in fisher behaviour following the introduction of new management strategies can generate unexpected outcomes, such as a shift towards targeting alternative species. Such changes can create new problems for management but even basic data are rarely available to predict the impacts of behavioural changes. Qualitative modelling can be a useful technique in data-limited situations to investigate potential shifts in management problems. This technique was used to investigate the effects of changes in fisher behaviour following the implementation of a seasonal fishing closure on a suite of high-value demersal scalefish. A simple 'core' model was used to investigate the dynamics involved in the general management of recreational fishing. A second more detailed model examined recreational fishing in the West Coast Bioregion of Western Australia. Similar results were obtained between the core and detailed models with an increased abundance of primary target species as a result of the closure and a decline in the alternative target species due to target-switching. A strong 'spike' in fishing effort following the re-opening of the fishery may actually increase fishing effort as a result of a seasonal closure. Additional management strategies, including increased recreational fishing restrictions were investigated. The study identified the need for an understanding of target switching, effort spikes and the 'value' placed on primary versus alternative target species.

Keywords: Fisher behaviour, effort spike, target switching, ecosystem model, fisheries management

1.0 Introduction

Despite numerous calls for the importance of recreational fishing to have greater acknowledgement in fisheries management (Kearney et al. 1996, Morales-Nin et al. 2005), there remains a paucity of long-term data on recreational fisheries, their impacts, and social and economic importance (Lewin et al. 2006). Recreational fishing may have similar impacts on fish stocks (Coll et al. 2004) and ecosystems (Lewin et al. 2006) as commercial fishing and, in certain areas, can form a greater proportion of the total catch than the commercial harvest (Kearney et al. 1996, McPhee et al. 2002). Recreational fishing can play an important role in the social dynamics of communities (Finn and Loomis 2001, Henry and Lyle 2003, Morales-Nin et al. 2005) and is a popular activity worldwide, for the provision of food (Burger 2002) and as a leisure activity (Henry and Lyle 2003). The capacity for fishers to change their behaviour at will, perhaps targeting an alternative species (Gentner 2004) or travelling further to fish (Arlinghaus 2005), determines that managers must consider potential changes in fisher behaviour when assessing the overall impact of a recreational management strategy on an ecosystem.

Behavioural changes, such as a movement to alternative target species or gear types, have the capacity to yield fisheries management ineffective in an ecosystem context through shifting effort to other stocks or increasing fishing efficiency (Gentner and Sutton 2007). For instance, investigation into commercial fisher behaviour after a netting ban in Florida found the majority of fishers altered capture methods or target species in order to continue fishing (Smith et al. 2003). Following the decline of groundfish stocks in Nova Scotia, commercial fishers were observed to fish further from their homeport (Binkley 2000), thereby shifting their effort and potentially causing sustainability issues elsewhere. As a result of the potential impact of such changes, fisheries managers may benefit from the *a priori* investigation of fisher behaviour to determine the likely effectiveness and overall impact of new strategies. To gauge the likely effectiveness of new recreational management, it is just as important to recognise how recreational fishers might change their behaviour following the implementation of the new measures (Woodward and Griffin 2003).

Qualitative modelling was used to investigate the overall impact of changes in the recreational fisheries management of a suite of key demersal species in the marine waters of south-western Australia. This region was used as a case study; the methods can be applied to investigate fisheries management issues in other situations. The qualitative modelling techniques used do not require quantitative estimates of the impacts of change (or perturbation) and can therefore be a useful technique in data-poor situations. For instance, the technique may be useful where the magnitude of change in fisher behaviour is unknown. These models were first used in ecology by May (1973) and Levins (1974) to depict trophic webs, investigate system stability and predict the direct and indirect effects of a perturbation on other variables in the system. While qualitative models do not provide an estimate of the magnitude of change, an assessment of the likely trends in ecosystem dynamics may be more feasible for management than determining appropriate reference points for change in each variable (Rochet et al. 2005). In addition, qualitative modelling may be used to investigate system structure as well as highlight important relationships, impacts and data gaps within fisheries management systems (Hayes et al. 2008, Metcalf et al. 2008). This technique also provides a tool with which to examine the potential impacts of alternative management strategies. As such, qualitative modelling may be of particular use as a tool to assess the likely efficacy of new management strategies.

2.0 Material and Methods

2.1 Study region

This study was undertaken in the West Coast Bioregion, a management region of the Government of Western Australia (Fig. 1) that includes the marine waters for approximately 560km of coastline. The West Coast Bioregion contains roughly 81% of the population of Western Australia (1.98 million people) and an estimated 457 300 of these people participate in recreational fishing (including fishing on charter boats) at least once a year (Barharthah 2008, www.fish.gov.au). To reduce fishing effort for demersal fish in this region, the commercial sector underwent considerable rationalization in 2007, effectively reducing fleet size by an order of magnitude and banning commercial fishing for demersal scalefish in the metropolitan zone (Fig. 1). A high level of recreational fishing effort remained in the region and the breeding-stock biomass of dhufish (*Glaucosoma herbraicum*) and pink snapper (*Pagrus auratus)* were recently reported as declining and low respectively (Western Australian Department of Fisheries 2008).

In 2009, a seasonal closure was proposed for the recreational fishing of a suite of demersal fish species, including dhufish, breaksea cod (*Epinephelides armatus*) and pink snapper in the West Coast Region. The seasonal closure would occur for two months per year (mid-October – mid-December) with the aim of reducing the capture of demersal fish within the suite. During this period, recreational fishing for other species would be allowed. Potential changes in fisher behaviour during the implementation of a seasonal are unknown. Qualitative models were produced to investigate potential behavioural changes and the impacts that these changes may have on stock sustainability.

2.2 Qualitative modelling and press perturbation

The relative growth of populations or species can be described by a graph, known as a signed digraph (Puccia and Levins 1985), which displays interactions between variables using interaction signs (+, -, 0). For instance, the relationship between a predator and its prey will be represented by a positive direct effect to the predator (arrow) and a negative direct effect (closed circle) to the prey (Fig. 2a). In this example, *Large fish* prey on *Small fish* while the *Fishery* targets both *Large* and *Small fish*. Density-dependence and a reliance on factors external to the system are represented through negative self-effects. For example, if a species continues to increase in abundance, there may eventually be negative repercussions on birth rates due to resource limitation. Abundance would then decline until resource limitation is no longer an issue. Similarly, if fishing activity for a group of fishers is limited by weather and costs (factors external to the system), a negative self-effect to the fisher variable can be used to represent this limitation.

Press perturbations (disturbances) may affect the dynamics of a system over a sustained period of time and may arise from long-term changes to one or more system parameter (Bender et al. 1984). A sustained increase in fishing pressure would be classed as a press perturbation. The community matrix **A** (Levins 1968, Puccia and Levins 1985) is composed of the direct effects (links) between variables (or species). For instance, there is a direct effect from predator to prey as a predator will cause a reduction in the abundance of prey, however, the predator may not have a direct effect on the abundance of primary producers that the prey feeds on. The adjoint of the negative community matrix (adj. –**A**, Table 1) details the predictions of response (+, -, 0) to press perturbations and accounts for both direct and indirect affects of change (Dambacher et al. 2002, 2005). Taking indirect affects into account, a perturbation may result in predictions of change in variables that are not directly impacted by the perturbation. When using qualitative modelling, press perturbations are usually shown in the adjoint matrix as an increase in the abundance of a specific variable.

Each prediction in the adjoint matrix represents a sum of positive and negative feedback cycles (Dambacher et al. 2002) (Table 1), here termed complementary feedback cycles. The specific complementary feedback cycles that contribute to predictions may be identified to determine the relationships driving each response (Dambacher et al. 2005). Each cycle consists of the links from the perturbed variable to the impacted variable and the complement, which consists of links not included in the chain of interactions from the perturbed to the impacted variable. Two complementary feedback cycles are involved in response of the *Fishery* to an increase (perturbation) in *Large fish* (Fig. 2b and c, Table 1). In the negative cycle, *Large fish* have a negative impact on the *Fishery* by reducing the abundance of *Small fish* captured in the *Fishery* (Fig. 2b). In contrast, in the positive cycle, *Large fish* have a direct positive impact on the *Fishery* (Fig. 2c). Figure 2c also shows the separation of the complement and the links from the perturbed variable to the variable of interest. In this case, the complement consists of the negative self-effect on *Small fish*.

Ambiguity in the prediction sign occurs when both positive and negative responses contribute to a prediction. If one positive and one negative response exists for a given perturbation, as in Figure 2, the predicted response will be ambiguous because there is an equal chance of the response being positive or negative. In contrast, if all responses are of the same sign, the prediction will be unambiguously (i.e. completely) determined. A measure of the level of sign indeterminacy is important. Sign indeterminacy refers to the possibility that the predicted response may be overwhelmed by a strong response in the opposing sign, resulting in an unexpected change (for further detail refer to Dambacher *et al*., 2002). These subtleties can be important for the ecological understanding of a system, as they can be used to assess system dynamics in regard to the relative strength of the links between variables. 'Average proportion of correct sign' (Hosack *et al.*, 2008) was used as an indication of sign indeterminacy. 'Correct' sign refers to signs produced during the Monte Carlo procedure (see Hosack *et al.*, 2008) that were consistent with the sign observed in the original model. Variables that produce high (>0.80, Hayes *et al*., 2008) 'average proportion of correct sign' are less likely to result in an unexpected response due to a strong response in one direction.

2.3 Model building and reasoning

A simple 'core' model was produced to investigate the relationships that may drive the overall impact of the seasonal closure on fish populations in the West Coast Bioregion. Following the production of this model, a detailed model including all potential changes in fisher behaviour in the focal bioregion was produced.

i) 'Core' model

The core model focuses on a generalised fishery management system in which multiple species are targeted but some (*Primary target species*) are more highly valued than others (*Alternative target species*) (Fig. 3). The variable, *Fishing*, was used to represent fishers or fishing effort and had a direct negative link to both the *Primary* and *Alternative target species* through the capture and removal of individuals. In contrast, *Fishing* was positively impacted by both target variables.

Fisheries management was used to represent a seasonal closure and was assumed to have a direct negative link to *Fishing* as a result of the restriction on effort for part of the year. The seasonal closure would also be expected to reduce the capture of the *Primary target species* by *Fishing*, thereby positively impacting the abundance of the *Primary target species*. Target switching, whereby fishers 'switch' from the *Primary target species* to *Alternative target species* during the closure, was also suggested to be likely by experts (S.J. Metcalf, unpublished data). For instance, during the closed season fishers may chose to target smaller nearshore species instead of the larger more valuable *Primary target species*. Such switching between targeted species is equivalent to prey switching in ecological systems (Hendee and Burdge 1974, Oaten and Murdoch 1975) and was shown in the model through a negative link from *Fisheries management* to *Alternative target species*, This is a modified interaction (Dambacher and Ramos-Jiliberto 2007), whereby a switch in preference to the *Alternative target species* essentially strengthens the links between *Fishing* and this target variable.

The impacts of an increase in *Fisheries management* (implementation of a seasonal closure) were investigated using the adjoint of the negative community matrix (adj. -**A**) to identify which paths and relationships may result in unexpected responses and should therefore be investigated in further detail.

ii) Model A: Fisher behaviour and a seasonal closure for key demersal fish species

Fishery managers, scientists, and stakeholders, such as recreational fishing representatives, were asked to suggest potential changes in fisher behaviour that may occur in the West Coast Bioregion following the implementation of a seasonal closure. Depending on the importance of recreational fishing to individual fishers, different behavioural responses were considered likely to occur, with disparate impacts on the fishery and fish stocks. For instance, people that previously fished once or twice a year within the West Coast Bioregion during the months of the closure may stop fishing altogether. Alternatively, people may travel to areas in which the closure is not in place (e.g. south or north coasts of Western Australia) or increase fishing effort for alternative species such as herring (*Arripis georgianus*) or samson fish (*Seriola hippos*) (e.g. Gentner 2004, Arlinghaus 2005). Fishers may also increase shore-based fishing if the protection of a large suite of demersal fish creates a disincentive for boat-based fishing during the closure (i.e. fishing not worth the boat trip). Each of these behaviours already exists in the West Coast Region; however, whether a change in the frequency of any behaviour or multiple behaviours would occur following the instigation of a seasonal closure is unknown.

A detailed model was produced to investigate all possible impacts on fish populations as a result of changes in fisher behaviour during a seasonal closure (Fig. 4). Fishing in Western Australia is managed according to the area in which fishing occurs. For instance, the capture of key demersal fish, such as dhufish and pink snapper, are managed in both nearshore (0-20m depth) and inshore (20-250m depth) areas (NB: these terms refer to local fisheries management areas). Two variables representing fishing in these management areas were included in the detailed model (*Nearshore fishing*, *Inshore fishing*), in addition to a *Demersal fish* variable. The *Demersal fish* variable included all species protected by the seasonal closure. Both nearshore and inshore fishers may capture other species, however, the capture of these species is stratified by depth. For instance, samson fish may be caught by fishers in deeper water (*Inshore fishing*, 20-250m depth) while fishers will catch herring closer to shore (*Nearshore fishing*, 0-20m depth). As a result, *Other nearshore species* and *Other inshore species* were included in the detailed model as separate variables. A *Shore-based fishing* variable was also included, targeting *Other nearshore species*.

An increase in fishing elsewhere (i.e. outside of the West Coast Bioregion) during a seasonal closure may occur if people decide to travel further to target their preferred demersal target species, which is protected during this period in the West Coast Bioregion. To represent this interaction, a *Fishing elsewhere* variable received a negative link from *Nearshore fishing* and *Inshore fishing*, as a decrease in fishing within the Bioregion (due to the seasonal closure) would cause an increase in the number of people fishing elsewhere. A *Fish elsewhere* variable was also included as a general resource for people fishing outside of the West Coast Region. Similarly to the core model, the press perturbation assessed in the model was an increase in *Fisheries management* through a seasonal closure on key demersal fish.

iii) Models B and C: Additional management strategies (to manage secondary target species)

Investigation into hypothetical additional management strategies was undertaken to combat any potential increases in the fishing mortality of the alternative species due to management changes invoked for the primary target species (i.e. seasonal closure Model A, Fig. 4). These additional strategies included additional restrictions on *Fishing elsewhere* in the state (Model B, Fig. 5a) and additional restrictions on fishing for *Other inshore species* and *Other nearshore species* within the West Coast Bioregion (Model C, Fig. 5b).

Additional restrictions on fishing outside of the West Coast Bioregion (Model B, Fig. 5a) were included in Model B through a direct negative link from *Fisheries management* to *Fishing elsewhere* (i.e. an effort reduction). All other management links remained the same as the model that included only a seasonal closure (Model A, Fig. 4).

Incorporating additional restrictions onto fishing for *Other inshore species* and *Other nearshore species* was achieved through the inclusion of a direct negative link to *Shore-based fishing* from *Fisheries management* as these fishers target *Other nearshore species* (Model C, Fig. 5b). A negative link from *Fisheries management* to *Inshore fishing* was already included in the model (Fig. 4) and it was therefore unnecessary to include additional links to represent reduced fishing effort. However, it was necessary to remove the direct links from *Fisheries management* to *Other nearshore species* and *Other inshore species*. Restricting the capture of these fish by reducing *Shore-based* and *Inshore fishing* determined that the negative link from management due to behaviour switching during the seasonal closure would no longer apply, as the additional management restrictions would be expected to positively impact these species. As the model represents a situation where the seasonal closure and additional restrictions would be acting simultaneously, it was assumed that the negative and positive links from *Fisheries management* cancelled one another (Fig. 5b).

3.0 Results

i) 'Core' model

An increase in fisheries management (seasonal closure), was predicted to negatively impact the *Fishery*, positively impact the *Primary target species* and negatively impact the *Alternative target species* (Shaded boxes, Table 2).

The responses of *Fishing* and *Alternative target species* to *Fisheries management* contained some ambiguity (average proportion of correct sign lower than 1.00) (Table 2). All other responses were completely determined. Two negative and one positive complementary feedback cycle contributed to the response of *Fishing* to a seasonal closure (*Fisheries management*) while three negative and one positive cycle contributed to the response of the *Alternative target species* (see Appendix A for symbolic adjoint matrix). Negative predictions of response for *Fishing* and the *Alternative target species* were observed in the adjoint matrix, as the positive cycle in each case was cancelled by one negative cycle, leaving a net negative response. This ambiguity remains important regardless of the negative prediction because a particularly strong positive path could override the two weaker negative paths, resulting in an increase in *Fishing* (through effort, number of participants) as a result of the seasonal closure. Investigating each path that contributed to ambiguity in the response of fishing was undertaken to highlight interactions that may cause non-intuitive responses to occur as a result of differing fisher behaviour (Fig. 6).

One negative path that contributed to the response of *Fishing* to *Fisheries management* was the direct negative path to this variable representing the short-term situation where an overall reduction in yearly fishing effort occurred as a result of the seasonal closure (Fig. 6a). Such a situation may also occur if some fishers stop fishing altogether due to the new management measures. The second negative path represents the situation where management caused fishers to switch to an alternative target, thereby reducing the abundance of *Alternative target species* and eventually creating a decline in *Fishing* (Fig. 6b). Finally, the positive path from *Fisheries management* to *Fishing* represents the situation where the seasonal closure allowed the *Primary target species* to increase in abundance and this, in turn, allowed fishing to increase (Fig. 6c). The public perception that a seasonal closure will increase the abundance of the target species could result in a 'spike' in fishing effort pre- and post-closure. A spike in fishing effort may also occur if fishers feel the need to 'fish while they can'. If the interactions in the path representing this spike in fishing effort are stronger than the decline in effort, due to a reduction in *Alternative target species* (Fig. 6b) and as a direct result of the seasonal closure (Fig. 6a), an increase in fishing may be observed.

ii) Model A: Fisher behaviour and a seasonal closure for key demersal fish species

The detailed model, based on the demersal recreational fishery in the West Coast Bioregion, displayed similar dynamics to the core model. All fish variables, excluding those protected during the seasonal closure, were predicted to decline in abundance due to an increase in management (Table 3). In addition, there was some ambiguity involved in the calculation of prediction signs for the response of *Nearshore* and *Inshore fishing* to an increase in *Fisheries management*. The change in these fishing variables due to a seasonal closure will depend on the strength of the links referred to in the core models as a 'spike' in fishing effort following the re-opening of the Bioregion to fishing. Similarly, if these links were strong, an overall increase in fishing (throughout the year) as a result of the seasonal closure would be expected.

iii) Models B and C: Additional management strategies (to manage secondary target species)

All models (A, B and C) predicted an increase in *Demersal species* as a result of a perturbation (increase) to *Fisheries management* with relatively high sign determinacy (Table 3). Model B, with additional restrictions on *Fishing elsewhere*, predicted reductions in all variables excluding *Demersal species* and *Fish elsewhere* in response to an increase in *Fisheries management*. In contrast, Model C predicted increases in *Other nearshore species* and *Other inshore species*, as well as an increase in *Nearshore fishing* with additional regulations on *Shore-based fishing*. These results occurred due to indirect positive impacts from management. For instance, in Model

C, greater catch restrictions for *Other nearshore species* allowed these fish to increase in abundance and positively impact *Nearshore fishing* through increased catch. This model also predicted a decline in *Fishing elsewhere*, because an increase in fishing in the West Coast Bioregion (through increased fish abundance and *Nearshore fishing*) would reduce the incentive for fishers to travel elsewhere. In Model C, the average proportion of correct sign was relatively low for both *Fish elsewhere* and *Other inshore species*, however, this strategy is likely to be more effective than the other strategies employed as all fish variables are predicted to increase in abundance.

4.0 Discussion

The qualitative modelling techniques undertaken in this study, while focussing on a Western Australian case study could be used to identify likely changes in system dynamics following perturbation or management change in any region. The technique can be particularly valuable as a management tool to highlight the range of potential outcomes prior to data collection and the implementation of new management strategies. The core and detailed qualitative models both identified the potential for the seasonal closure to increase the abundance of the protected primary target species, suggesting the strategy may achieve the aim of reducing the fishing mortality of these species. Such confirmation of management objectives, in conjunction with similar results from other models and quantitative analyses, may serve to reduce the uncertainty involved in the response to management (Sainsbury et al. 2000, Nagy et al. 2007) and be useful in the decision-making process. In previous studies, seasonal closures have been suggested to be effective for species with seasonal migrations (Hunter et al. 2004) or long-lived, late-maturing species as well as those susceptible to sex ratio bias, such as hermaphrodites (Heppell et al. 2006). However, if the aim of management is to protect a large suite of species, as in this case study, it will be unlikely that all species will benefit to the same extent from a seasonal closure. As a result, it is critical that the closure is implemented at an appropriate time to maximise the protection of the most vulnerable fish populations and is of an appropriate length to reduce fishing effort by the required amount.

In addition to predicting the response of the protected species during the seasonal closure, the qualitative models also allowed the identification of less-intuitive responses through the examination of the specific paths and feedbacks involved in each prediction (Puccia and Levins 1985, Dambacher et al. 2002). The ability to identify these interactions is useful for management as it can allow the identification of potential behavioural changes that may otherwise go unnoticed, thereby reducing the effectiveness of management (Rijnsdorp et al. 2001, Cox and Walters 2002). For instance, the models illustrated a path through which a large change in the perception of catch rates of the primary target species (an increase) by fishers could result in an increase in effort or an effort 'spike'. An increase in fishing effort pre- and post-closure may undermine the benefit to the demersal species from the seasonal closure by increasing, rather than decreasing, effort. While qualitative models generally assume all links have equal strength, when a response has both positive and negative feedback cycles (has a level of ambiguity) the strength of the links becomes important. This effort spike would therefore only actually increase fishing effort if it was very large in comparison to the negative influence of introducing a seasonal closure, such as an overall reduction in fishers in the region. The potential for such spikes in fishing effort to occur have been observed around the world in both commercial (Rijnsdorp et al. 2001) and recreational (Jackson et al. 2005, Meyer 2007) fisheries following the implementation of closures. The recognition that such behavioural change may occur is important because a high preand/or post-closure effort spike may exceed the effort reductions achieved by the closed season. As a result, the protected species may actually decline in abundance following the implementation of a seasonal closure.

The qualitative models indicated that changes in fisher behaviour may cause an increase in the overall effort directed towards alternative target species and a subsequent decline in their abundance. This corresponded to the opinions of experts who suggested target switching was likely to occur following the seasonal closure. Target switching in commercial fisheries, according to changing economic values or variations in abundance, is a relatively common occurrence (Katsukawa and Matsuda 2003). However, this switching behaviour has rarely been investigated in recreational fisheries, despite the potential implications for management efficiency (Sutton and Ditton 2005).

In order to combat a potential spike in fishing effort and target switching to alternative species, the monitoring of fisher behaviour and education of recreational fishers by fisheries management agencies needs to be improved. Fishers should be informed of the time-scale involved in the recovery of the stocks, including clarification that an increase in catch rates due to a seasonal closure would not occur for a number of years. Indeed, for long-lived species that reach maturity at ages greater than four years, such as many of the key species within the suite of demersal fish (Lenanton et al. 2009), it is biologically impossible for any recovery of the vulnerable age/size classes in under four years. The recreational fishing community also needs to be made aware that any spikes in effort would subsequently need to be dealt with by the introduction of further restrictions in fishing effort.

Qualitative models can be of particular benefit in highlighting areas of concern for management, which could then be used to support an argument for data collection in data-limited systems. Data collection is critical as management strategies are more likely to fail when basic data are lacking (Post et al. 2003). Qualitative models are not the only method available for investigating data-limited ecosystems and fisheries. For instance, angler surveys and tournament data have been used in Brazil (Freire 2005) and Ecosim and Ecospace were used in the South China Sea (Cheung and Pitcher 2005). The information obtained by Friere (2005) could be further assessed through the use of qualitative modelling. Similar to the current study, a model could be produced to investigate the likelihood of changes to different types of fishing and the potential impacts on the abundance of fish stocks. Such information could be used to supplement the results obtained regarding changes in the mean weight of fish and would require only trends over time rather than quantitative data. The capacity to produce qualitative models without detailed data means that this technique may require fewer assumptions than quantitative models such as Ecosim and Ecospace. Ecosim and Ecospace can be useful to provide information on general trends over time and space. However, they also have relatively large data requirements, which may increase the uncertainty of results and/or determine that the models cannot be produced in data-limited situations.

Data collection and further modelling of recreational fisher behaviour should be undertaken as part of Ecosystem Based Fisheries Management (EBFM). EBFM is the next step forward for fisheries management and can be considered as an operational extension of Ecologically Sustainable Development (ESD) (Fletcher et al. 2002). This form of management recognises the physical, biological, economic and social interactions among the affected components of the ecosystem and attempts to manage fisheries to achieve multiple, often competing social objectives (Marasco et al. 2007). As such, it is critical that social information, such as recreational fisher behaviour, is taken into account in the determination of management strategies. The qualitative modelling technique used in this study can predict trends in behaviour and species abundance that may be used to guide management towards sustainable fishing strategies using EBFM.

5.0 Acknowledgements

This study was funded by the Western Australian Marine Science Institution (WAMSI). We would like to thank Jenny Shaw and Rick Fletcher for many useful comments and suggestions. Comments from Jeff Dambacher regarding the qualitative models were much appreciated. Thanks to Recfishwest, as well as Brett Molony, Rod Lenanton, Brent Wise, David Fairclough and Corey Wakefield from the Department of Fisheries, Western Australia. The authors also thank the reviewers for their useful comments.

6.0 References

Arlinghaus, R., 2005. A conceptual framework to identify and understand conflicts in recreational fisheries systems, with implications for sustainable management. Aq. Res. Cult. Dev. 12, 145-174.

Barharthah, T., 2008. Department of Fisheries community survey 2006. Department of Fisheries, Government of Western Australia, Perth.

Bender, E.A., Case, T.J., Gilpin, M.E., 1984. Perturbation experiments in community ecology: theory and practice. Ecol. 65, 1-13.

Binkley, M., 2000. "Getting by" in troubled times: Coping with the fisheries crisis. W. Stud. Int. For. 23, 323-332.

Burger, J., 2002. Consumption patterns and why people fish. Env. Res. 90, 125-135.

Cheung, W. W. L. and Pitcher, T. J. (2005) Designing fisheries management policies that conserve marine species diversity in the northern South China Sea. In: Kruse, G. H., Gallucci, V. F., Hay, D. E., Perry, R. I., Peterman, R. M., Shirley, T. C., Spencer, P. D., Wilson, B. and Woodby, D. (eds.) Fisheries assessment and management in data-limited situations. Alaska Sea Grant College Program, University of Alaska, Fairbanks, USA, pp. 439-466.

Coll, J., Linde, M., Garcia-Rubies, A., Riera, F., Grau, A.M., 2004. Spear fishing in the Balearic Islands west central Mediterranean: species affected and catch evolution during the period 1975-2001 Fish. Res. 70, 97-111.

Cox, S.P., Walters, C.J., 2002. Maintaining quality in recreational fisheries: how success breeds failure in the management of open-access fisheries. In: Recreational fisheries: Ecological, economic, and social evaluation. T.J. Pitcher and C. Hollingworth eds., Blackwell Science, Oxford, pp. 107-119.

Dambacher, J.M., Li, H.W., Rossignol, P.A., 2002. Relevance of community structure in assessing indeterminacy of ecological predictions. Ecol. 83, 1372-1385.

Dambacher, J.M., Levins, R., Rossignol, P.A., 2005. Life expectancy change in perturbed communities: Derivation and qualitative analysis. Math. Biosci. 197, 1-14.

Dambacher, J. M., Ramos-Jiliberto, R., 2007. Understanding and predicting effects of modified interactions through a qualitative analysis of community structure. Quart. Rev.Biol. 82 3, 227-250.

Finn, K.L., Loomis, D.K., 2001. The importance of catch motives to recreational anglers: the effects of catch satiation and deprivation. Hum. Dim. Wildl., 6, 173-187.

Fletcher W. J., Chesson J., Fisher M., Sainsbury K. J., Hundloe T., Smith A. D. M., Whitworth B. 2002. National ESD Reporting Framework for Australian Fisheries: the "How To" Guide for Wild Capture Fisheries. Fisheries Research and Development Corporation Project 2000/145, Canberra, Australia. 120 pp.

Friere, K. M. F. 2005. Recreational fisheries in Northeastern Brazil: Inferences from data provided by anglers. In: Kruse, G. H., Gallucci, V. F., Hay, D. E., Perry, R. I., Peterman, R. M., Shirley, T. C., Spencer, P. D., Wilson, B. and Woodby, D. (eds.) Fisheries assessment and management in data-limited situations. Alaska Sea Grant College Program, University of Alaska, Fairbanks, USA, pp. 377-394.

Gentner, B., 2004. Examining target species substitution in the face of changing recreational fishing policies. In: Proceedings of the twelfth biennial conference of the International Institute of Fisheries Economics and Trade, Tokyo, Japan, p.12.

Gentner, B., Sutton, S. 2007. Substitution in recreational fishing. In *Global challenges in recreational fisheries*. Eds. O. Aas, Blackwell Science, Oxford, p. 150-168.

Hayes, K.R., Lyne, V., Dambacher, J.M., Sharples, R., Smith R., 2008. Ecological indicators for the exclusive economic zone waters of the south west marine region. Final report 08/82 for the Australian Government, Department of the Environment and Heritage, CSIRO Marine and Atmospheric Research, Hobart, 152pp.

Hendee, J.C., Burdge, R.J., 1974. The substitutability concept: implications fir recreation research and management. J. Leis. Res. 6, 155-162.

Henry, G.W., Lyle, J.M., 2003. The national recreational and indigenous fishing survey. NSW Fisheries final report series, FRDC Project No. 99/158, 188pp.

Heppell, S.S., Heppell, S.A., Coleman, F.C., Koenig, C.C., 2006. Models to compare management options for a protogynous fish. Ecol. Appl. 161, 238-249.

Hosack, G.R., Hayes, K.R., Dambacher, J.M., 2008. Assessing uncertainty in the structure of ecological models through a qualitative analysis of system feedback and Bayesian belief networks. Ecol. App. 18, 1070-1082.

Hunter, E., Berry, F., Buvkley, A.A.Stewart, C., Metcalfe, J.D., 2004. Seasonal migration of thornback rays and implications for closure management. The

Centre for Environment, Fisheries and Aquculture Science, Lowestoft Laboratory. www.cefas.co.uk

Jackson, G., Sumner, N., Cribb, A., Norriss, J., 2005. Comparing conventional social-based and alternative output-based management models for recreational fisheries using Shark Bay pink snapper as case study. Fisheries Research and Development Corporation Final Report, Project 2003/066. Department of Fisheries Western Australia, Perth. 80 pp.

Katsukawa, T., Matsuda, H., 2003. Simulated effects of target switching on yield and sustainability of fish stocks. Fish. Res. 60, 515-525.

Kearney, R.E., Andrew, N.L., West, R.J., 1996. Some issues in the management of Australia's marine and coastal fisheries. Ocean Coastal Man. 33, 133-146.

Lenanton, R., St. John, J. (Project Principal Investigator 2003-07), Keay, I., Wakefield, C., Jackson, G., Wise, B., Gaughan, D. 2009. Spatial scales of exploitation among populations of demersal scalefish: implications for management. Part 2: Stock structure and biology of two indicator species, West Australian dhufish (*Glaucosoma hebraicum*) and pink snapper (*Pagrus auratus*), in the West Coast Bioregion. Final report to Fisheries Research and Development Corporation on Project No. 2003/052. Fisheries Research Report No. 174. Department of Fisheries, Western Australia. 187p. www.fish.wa.gov.au/docs/frr/frr174/frr174.pdf

Levins, R., 1968. Evolution in changing environments: some theoretical explorations. Princeton, New Jersey: Princeton University Press.

Levins, R., 1974. The qualitative analysis of partially specified systems. Ann. NY Acad. Sci. 231, 123-138.

Lewin, W.C., Arlinghaus, R., Riera, V., 2006. Documented and potential biological impact of recreational fishing: insight for management and conservation. Rev. Fish. Sci. 14, 305-367.

Marasco, R.J., Goodman, D., Grimes, C.B., Lawson, P.W., Punt, A.E., Quinn II, T.J., 2007. Ecosystem based fisheries management: some practical suggestions. Can. J. Fish. Aquat. Sci. 646, 928-939.

May, R. M. 1973. Qualitative stability in model ecosystems. Ecol. 54, 638-641.

McPhee, D.P., Leadbitter, D., Skilleter, G.A., 2002. Swallowing the bait: is recreational fishing in Australia ecologically sustainable? Pac. Cons. Biol. 8, 40-51.

Metcalf, S.J., Dambacher, J.M., Hobday, A.J., Lyle, J.M., 2008. Importance of trophic information, simplification and aggregation error in ecosystem models. Mar. Ecol. Prog. Ser. 360, 25-36.

Meyer, C.G., 2007. The impacts of spear and other recreational fishers on a small permanent marine protected area and adjacent pulse fished area. Fish. Res. 84, 301-307.

Morales-Nin, B., Moranta, J., Garcia, C., Tugores, M.P., Grau, A.M., Riera, F., Cerda, M., 2005. The recreational fishery off Majorca Island western Mediterranean: some implications for coastal resource management. ICES J. Mar. Sci 62, 727-739.

Nagy, L., Fairbrother, A., Etterson, M., Orme-Zavaleta, J. 2007. The intersection of independent lies: increasing realism in ecological risk assessment. Human Ecol. Risk Ass. 13, 355-369.

Oaten, A., Murdoch, W.W. 1975. Switching, functional response, and stability in predator-prey systems. Am. Nat. 109, 299-318.

Post, J.R., Mushens, C., Paul, A., Sullivan, M., 2003. Assessment of alternative harvest regulations for sustaining recreational fisheries: model development and application to bull trout. N. Am. J. Fish. Man. 23, 22-34.

Puccia, C. J., Levins, R., 1985. Qualitative modelling of complex systems. Cambridge, Massachusetts: Harvard University Press.

Rijnsdorp, A.D., Piet, G.J., Poos, J.J., 2001. Effort allocation of the Dutch beam trawl fleet in response to a temporarily closed area in the North Sea. Theme session on case studies in the systems analysis of fisheries management. International Council for the Exploration of the Sea. CM 2001/N:01, 17pp.

Rochet, M.-J., Trenkel, V., Bellail, R., Coppin, F., Le Pape, O., Mahe, J.-C., Morin, J., Poulard, J.-C., Schlaich, I., Souplet, A., Verin, Y., Bertrand, J., 2005. Combining indicator trends to assess ongoing changes in exploited fish communities: diagnostic of communities off the coasts of France. ICES J. Mar. Sci. 62, 1647-1664.

Sainsbury, K. J., Punt, A. E., Smith, A. D. M. 2000. Design of operational management strategies for achieving fishery ecosystem objectives. ICES J. Mar. Sci. 57, 731-741.

Smith, S., Jacob, S., Jepson, M., 2003. After the Florida net ban: the impacts on commercial fishing families. Soc. Nat. Res. 16, 39-59.

Sutton, S.G., Ditton, R.B., 2005. The substitutability of one fishing type for another. N. Am. J. Fish. Man. 25, 536-546.

Western Australian Department of Fisheries, 2008. State of the fisheries report 2007/08. Department of Fisheries, Western Australia, Perth, Australia. www.fish.wa.gov.au/

Woodward, R.T., Griffin, W.L., 2003. Size and bag limits in recreational fisheries: theoretical and empirical analysis. Mar. Res. Econ. 18, 239-262.

Figure 1. Map of Western Australia showing the Department of Fisheries bioregional boundaries (Western Australian Department of Fisheries 2008) and the location of the metropolitan (metro.) zone in which commercial fishing for demersal fish species is banned.

Figure 2. Signed digraph representing a) the direct effects between predators (i.e. *Fishery* and *Large fish*) and their prey (i.e. *Large fish* and *Small fish*). The predators have negative direct effects on the prey ( ) while the prey have positive direct effects on the predators ( ). Negative self-effects represent density-dependence or a reliance on factors external to the system. The two complementary feedback cycles through which *Large fish* impact the *Fishery* are shown (b and c). The complement was shown for the positive path, while no complement exists in the negative path, as all variables were involved in the links from *Large fish* to the *Fishery*.

Figure 3. The core model showing the relationship between fisheries management, fishing and the target species due to a seasonal closure, during which the capture of *Primary target species* is prohibited.

Figure 4. Model A, representing recreational fishing for demersal fish species in the West Coast Region and elsewhere in Western Australia. The links from the *Fisheries management* variable represent a seasonal closure in the West Coast Bioregion.

Figure 5. Models representing recreational fishing in the West Coast Region with additional management regulations for the protection of secondary target species. a) additional restrictions on *Fishing* elsewhere (Model B), and b) additional restrictions (e.g. decrease bag or size limits) on fishing for *Other inshore species* and *Other nearshore* species (Model C) were included through negative links to *Shore-based fishing*, *Nearshore fishing* and *Inshore fishing*. Similarly to Model A (Fig. 4), a seasonal closure was included in Models B and C as well as the additional management strategies.

Figure 6. Paths from *Fisheries management* (seasonal closure) to *Fishing*. Paths a) and b) are negative and will result in a decrease in *Fishing*, while path c) represents a ‘spike’ in fishing effort outside of the closed season and, if stronger than the two negative paths, may result in an increase in *Fishing* due to the seasonal closure.

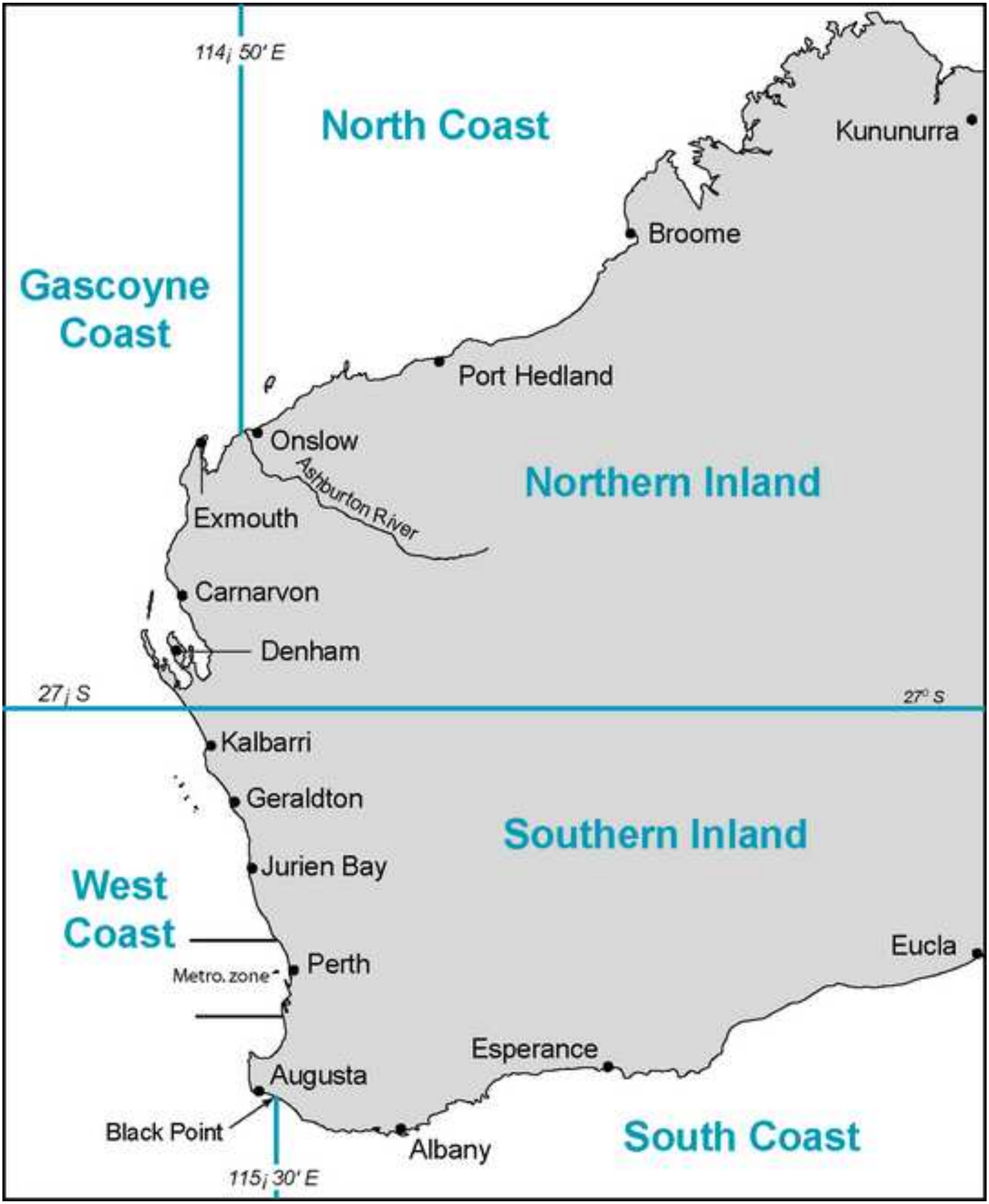
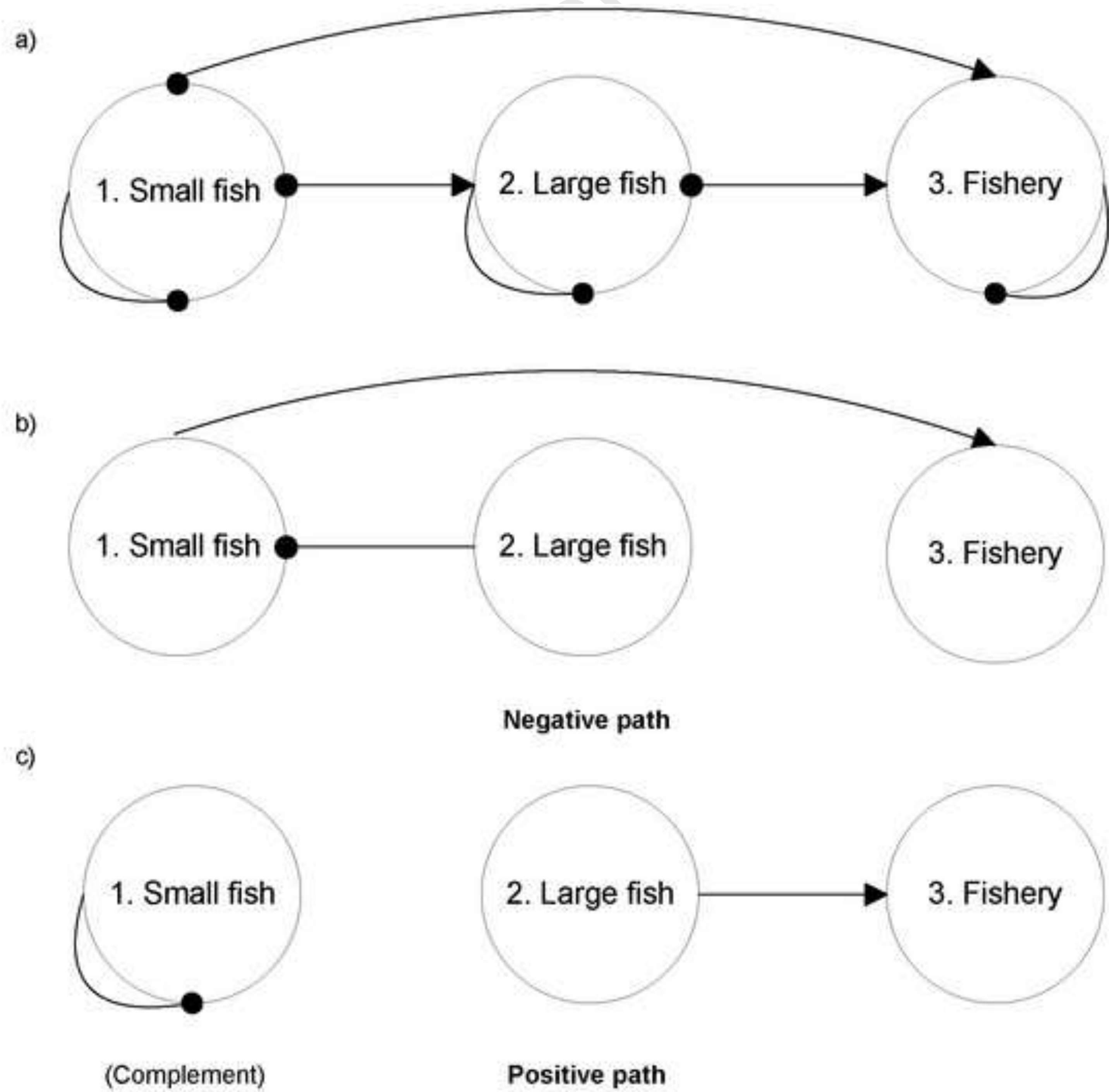

114¡ 50′ E
North Coast
Kununurra
Broome
Gascoyne Coast
Port Hedland
Onslow
Ashburton River
Northern Inland
Exmouth
Carnarvon
Denham
27¡ S
27° S
Kalbarri
Geraldton
Southern Inland
Jurien Bay
West Coast
Perth
Metro. zone
Eucla
Esperance
Augusta
Black Point
Albany
South Coast
115¡ 30′ E

Figure 2


a)
1. Small fish
2. Large fish
3. Fishery
b)
1. Small fish
2. Large fish
3. Fishery
Negative path
c)
1. Small fish
2. Large fish
3. Fishery
(Complement)
Positive path

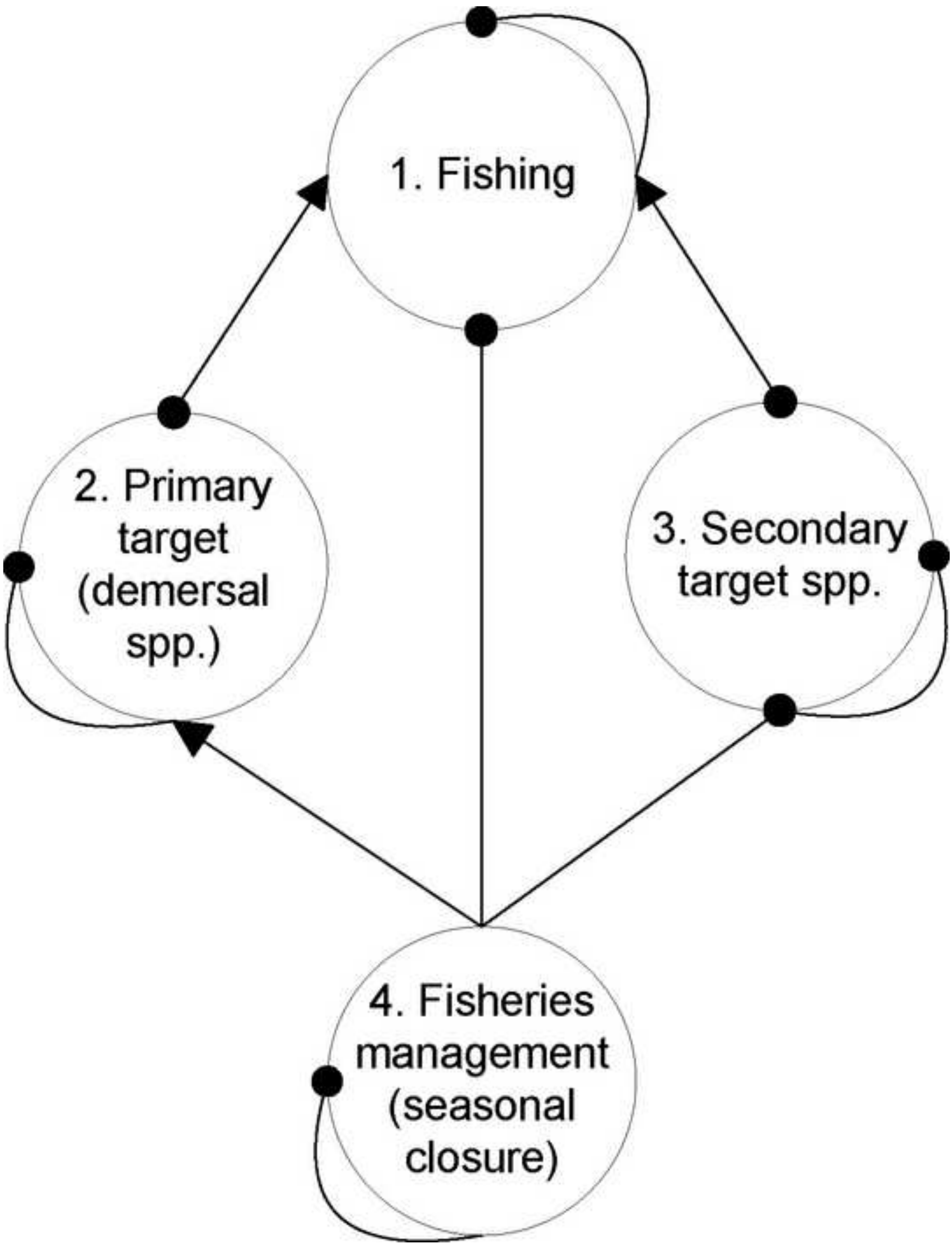
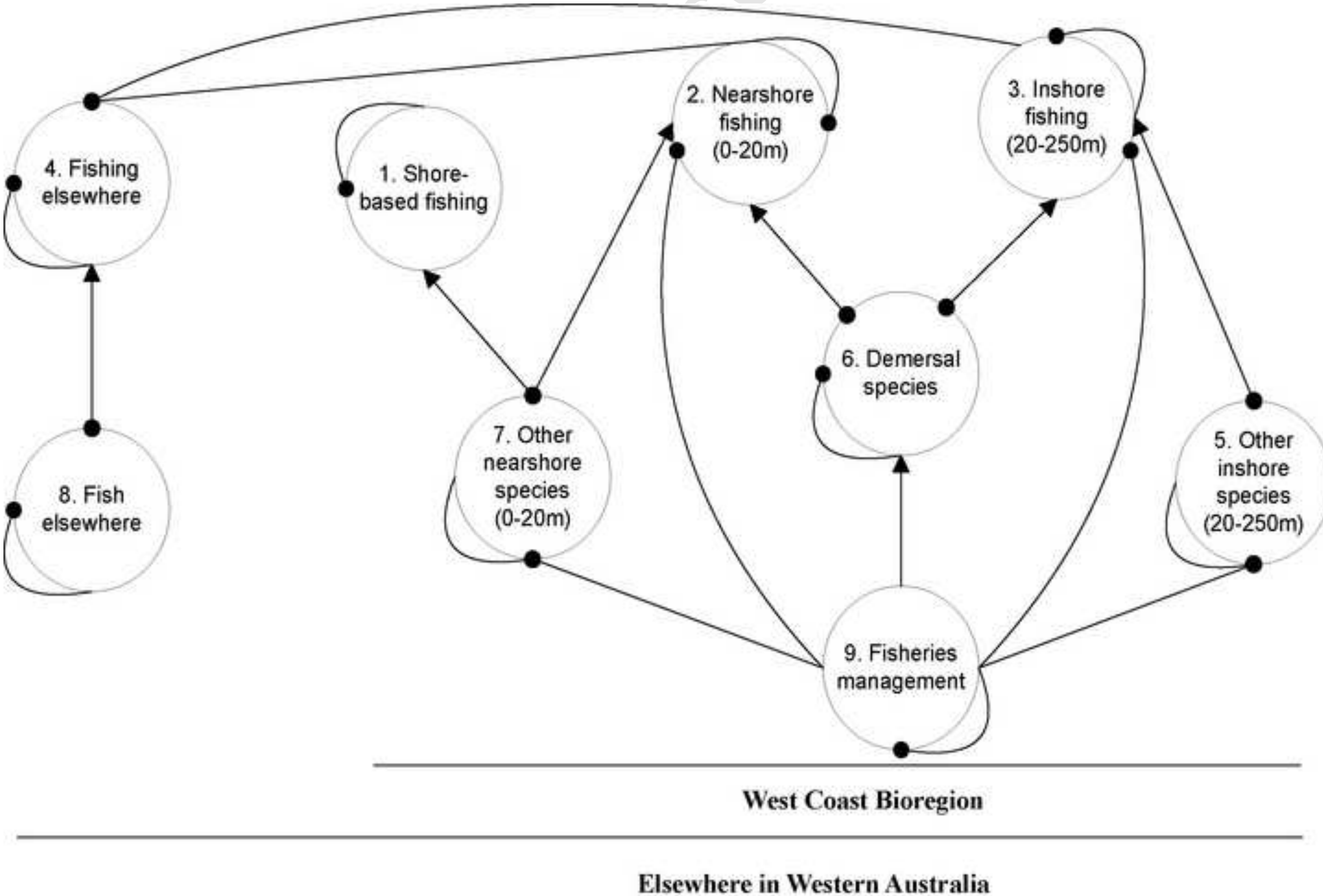
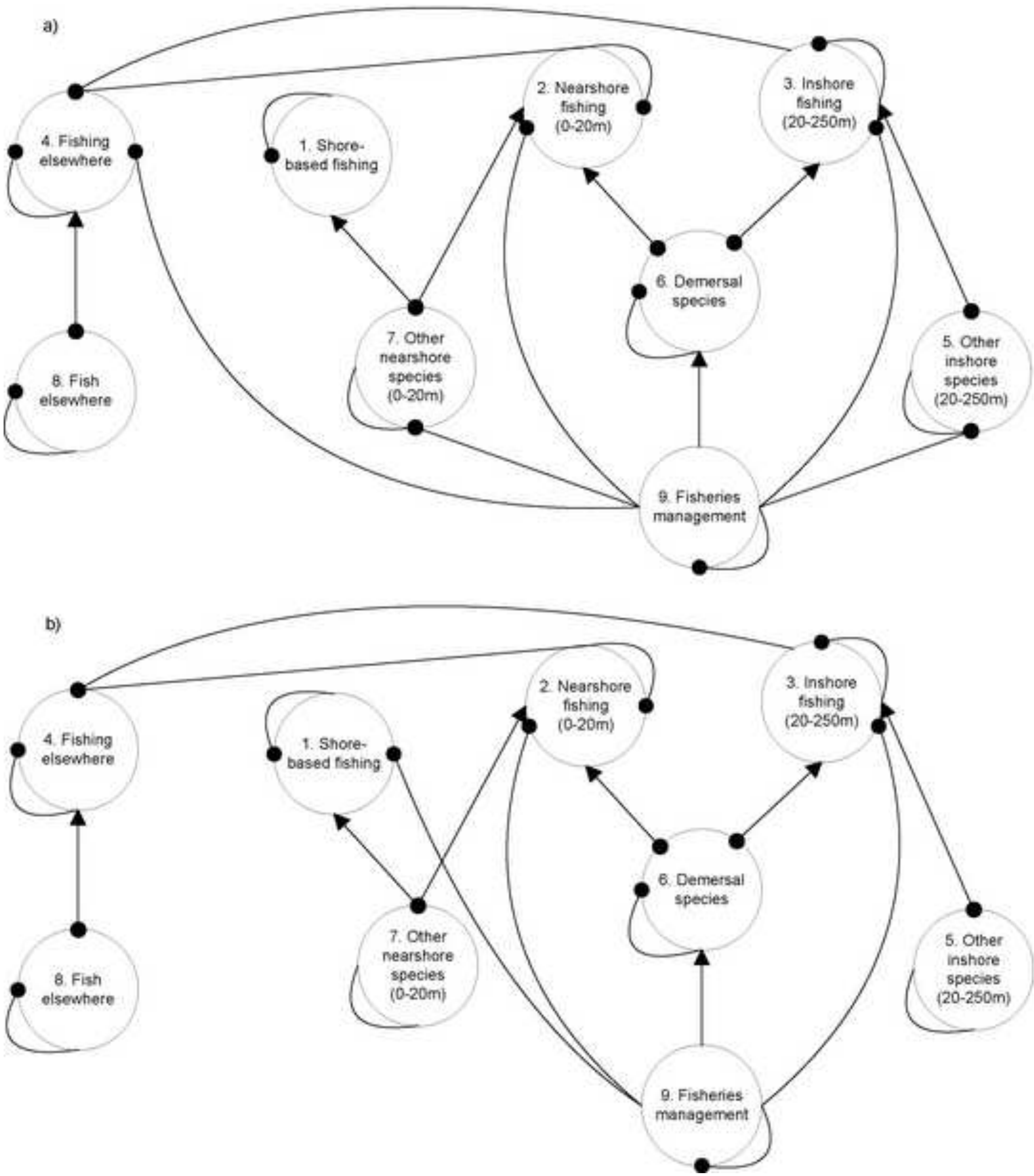

1. Fishing
2. Primary target (demersal spp.)
3. Secondary target spp.
4. Fisheries management (seasonal closure)

Figure 4



4. Fishing elsewhere
1. Shore-based fishing
2. Nearshore fishing (0-20m)
3. Inshore fishing (20-250m)
6. Demersal species
8. Fish elsewhere
7. Other nearshore species (0-20m)
5. Other inshore species (20-250m)
9. Fisheries management
West Coast Bioregion
Elsewhere in Western Australia


a)
1. Shore-based fishing
2. Nearshore fishing (0-20m)
3. Inshore fishing (20-250m)
4. Fishing elsewhere
5. Other inshore species (20-250m)
6. Demersal species
7. Other nearshore species (0-20m)
8. Fish elsewhere
9. Fisheries management
b)
1. Shore-based fishing
2. Nearshore fishing (0-20m)
3. Inshore fishing (20-250m)
4. Fishing elsewhere
5. Other inshore species (20-250m)
6. Demersal species
7. Other nearshore species (0-20m)
8. Fish elsewhere
9. Fisheries management

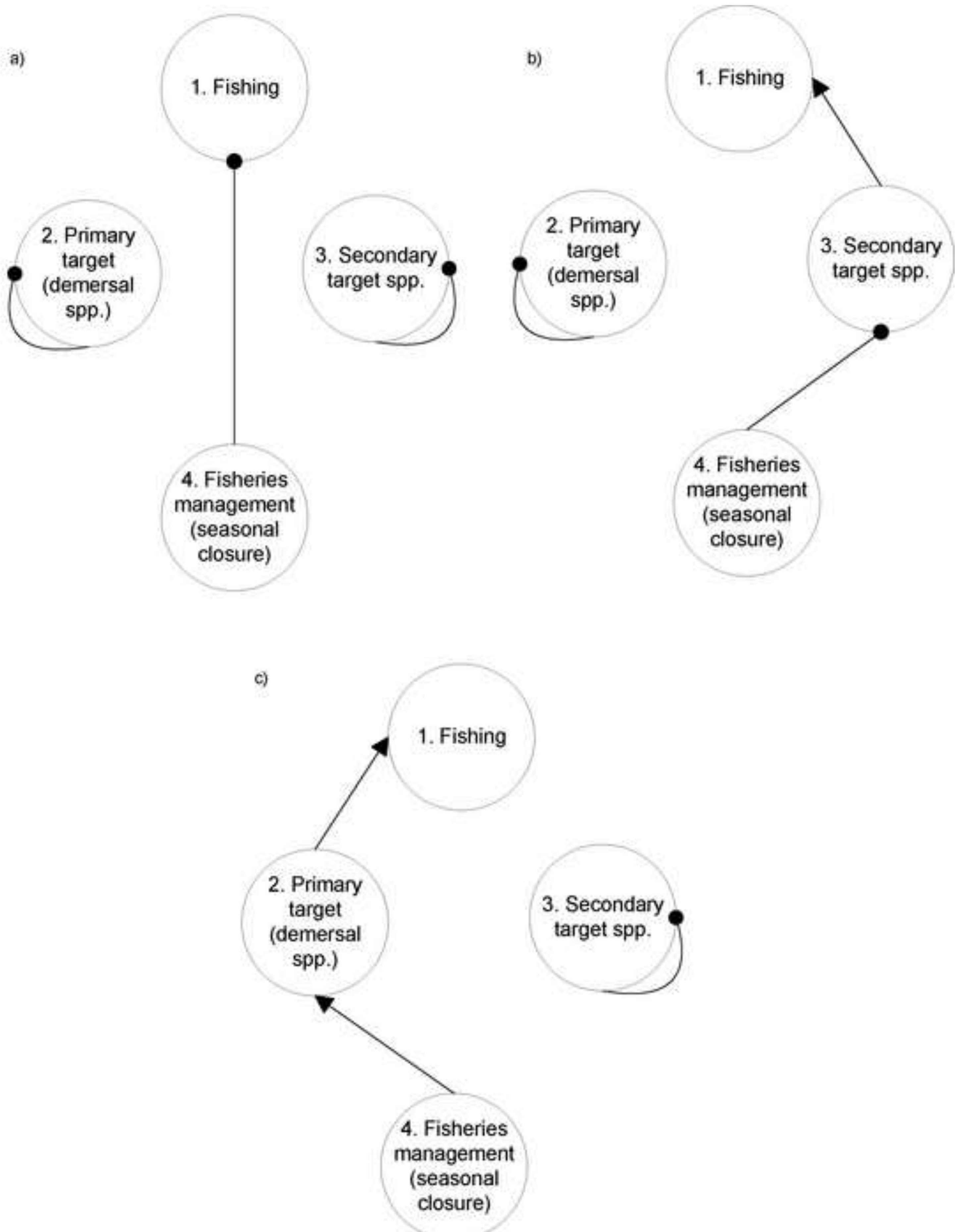

a)
1. Fishing
2. Primary target (demersal spp.)
3. Secondary target spp.
4. Fisheries management (seasonal closure)
b)
1. Fishing
2. Primary target (demersal spp.)
3. Secondary target spp.
4. Fisheries management (seasonal closure)
c)
1. Fishing
2. Primary target (demersal spp.)
3. Secondary target spp.
4. Fisheries management (seasonal closure)

Table 1. Predictions of the direction of response to perturbation for the signed digraph in Figure 2. Perturbations are read down the columns while the predicted directions of response are read across rows. Signs inside parentheses display the signs of all feedback cycles associated with the response. Prediction signs are the sum of these positive and negative feedback cycles. The shaded response is shown in the digraphs in Figure 2b and c.

Predictions from the Adjoint matrix	*Small fish*	*Large fish*	*Fishery*
Small fish	+ (+,+)	- (-, -)	0 (+, -)
Large fish	0 (+, -)	+ (+,+)	- (-, -)
Fishery	+ (+,+)	0 (+, -)	+ (+,+)

Table 2. Predicted responses to perturbation from the adjoint matrix (adj. – **A**) and average proportion of correct sign for the core model. In this table 0 shows that *Fishing*, *Primary target species* and *Alternative target species* have no impact on *Fisheries management* as opposed to an ambiguous response, which was represented by 0 in Table 1.

Variable	*Fishing*	*Primary target species*	*Alternative target species*	*Fisheries management*
Fishing Average prop. correct sign	+ 1.00	+ 1.00	+ 1.00	- 0.77
Primary target species Average prop. correct sign	- 1.00	+ 1.00	- 1.00	+ 1.00
Alternative target species Average prop. correct sign	- 1.00	- 1.00	+ 1.00	- 0.87
Fisheries management Average prop. correct sign	0 1.00	0 1.00	0 1.00	+ 1.00

Table 3. Predicted responses to an increase in *Fisheries management* for detailed models including a seasonal closure alone (Model A, Fig. 4), a seasonal closure and restrictions on *Fishing elsewhere* (Model B, Fig. 5a), and a seasonal closure and restrictions on fishing for *Other inshore species* and *Other nearshore species* (Model C, Fig. 5b).

Variable	**Model A** **(Fig. 4)** Seasonal closure	**Model B** Additional management strategy: Restrictions on *Fishing elsewhere*	**Model C** Additional management strategy: Restrictions on fishing for *Other inshore species* and *Other nearshore species*
Demersal species Average prop. correct sign	+ 1.00	+ 1.00	+ 0.97
Nearshore fishing Average prop. correct sign	- 0.57	- 0.57	+ 0.71
Other nearshore species Average prop. correct sign	- 0.90	- 0.90	+ 0.87
Fishing elsewhere Average prop. correct sign	+ 0.67	- 0.71	- 0.58
Shore-based fishing Average prop. correct sign	- 0.90	- 0.90	- 0.92
Inshore fishing Average prop. correct sign	- 0.77	- 0.77	- 0.60
Fish elsewhere Average prop. correct sign	- 0.67	+ 0.88	+ 0.58
Other inshore species Average prop. correct sign	- 0.90	- 0.90	+ 0.60